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METEOROLOGICAL APPLICATIONS OF EARTH SATELLITES*

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Introduction. When it was first announced that definite plans had been laid for the launching of earth satellites during the International Geophysical Year, meteorologists realized that such satellites could be of inestimable value to them. Preliminary planning took cognizance of this interest and led to the specification of two purely meteorological experiments. The chief advantages of a satellite as an observational vehicle are: it operates above the atmosphere, it can view a large area of the earth in a short period of time and it can be maintained in space for a long period of time. Its chief limitations are: observations over different areas are not simultaneous, it cannot transmit intelligence on a continuous basis and it is a rather expensive tool for meteorological purposes, although this would not necessarily be true for upper atmosphere studies in general. Over oceans and other areas of sparse data (especially in the southern hemisphere), satellite information will be invaluable, provided that it is reasonably specific and unambiguous.

Only an orbit passing over the poles would permit an overhead scan at all latitudes, and this is a vital consideration in the case of meteorological parameters, for which the variation in space is generally more important than the variation in time. The height of the orbit is not nearly so critical for meteorological purposes, and tracking facilities would also not be extended by purely meteorological requirements. Satellite orienta-

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tion would, however, pose a difficult problem since radiation streams (by which the satellite observes the atmosphere) are definitely not isotropic. For many experiments, spin-stabilization (about vertical or horizontal axes) would appear necessary. A final operational consideration is that of data transmission (by line of sight telemetering), necessitating data storage during an orbit. This implies that accuracy can only be increased at the expense of resolution, by a large-area sampling.

The Albedo Experiment. The ratio of the radiation reflected by a body to that incident on it is known as its albedo. The albedo of the earth plus atmosphere, for solar radiation, plays a critical role in the radiation budget of our planet and thus in specifying the manner in which the general circulation of the atmosphere must operate, to balance this budget. The major contribution to the planetary albedo comes from clouds, and neither theory nor observational data are adequate to predict this contribution on a routine basis.

At present, the only check on estimates of global albedo is that provided by observations of the relative brightness of the sunshine and earthshine on the moon. The influence of terrestrial cloudiness on lunar earthshine was, in fact, the subject of a paper presented by Kimball (1901), of the U.S. Weather Bureau, to the Toronto Astronomical and Physical Society in June 1901. According to French observations on the moon (Danjon, 1954 and Dubois, 1955), the visual albedo is 0.40, on the average, and varies quite markedly from month to month, and, for a given month, from year to year.

The chief reason why the albedo experiment is the primary meteorological objective of the U.S. satellite programme is simply that a measurement of visual albedo is precisely equivalent to a photograph of the earth and of its cloud cover. An ideal arrangement would be to use a television camera in a satellite. To take maximum advantage of the high resolution available with such a system, one would use a high-altitude orbit—for example, at 4,000 miles with a period of about four hours. Initially, a far cruder programme is planned, with a low-level orbit and a photocell detector, scanning over a narrow strip normal to the satellite orbit, with a resolution of about ten miles. Such cloud data could rather easily be integrated into conventional analysis and forecasting routine, and would be particularly valuable in giving warning of incipient depressions over ocean areas.

Radiation Balance Experiment. Fundamental information on the driving force of the general circulation is provided by the radiation balance

at outer space, and it would clearly be highly advantageous to have this parameter measured continuously, as a function of both space and time, over very long time intervals. In order to interpret or explain this radiation balance, it is necessary to be able to differentiate between radiation in various wave-length regions (solar visible plus ultra-violet, solar near infra-red and terrestrial far infra-red, for example). This can best be done with a pair of parallel-plate radiometers, whose receiving surfaces have absorptive properties which vary with wave-length.

If the separate energy components in this radiation budget are known, and if simultaneous cloud pictures are available in one or more spectral regions, it should be possible to formulate the energy balances of the earth and atmosphere, separately. Robinson (1956) has shown how this can be done from surface radiation records alone, by the use of various spectral domains and a minimum of assumptions. Certainly, a combination of satellite data and complete radiation data from a small number of stations should permit an accurate assessment and explanation of all radiation balance terms.

Radiation Balance and the General Circulation. Numerous estimates have been made of the radiation balance of the earth and atmosphere, of the disposition of solar radiation, and of the energy budget of the earth and atmosphere. Many items in these budgets are only approximate at best, but it is of interest to examine one such budget, prepared by Raethjen (1950), in order to appreciate the interdependence of radiation balance and the general circulation. Table I gives the solar energy

TABLE I

DISPOSITION OF SOLAR RADIATION, IN KLY (10^3CAL./CM.^{2}) PER HALF-YEAR

	Winter				Summer		
Latitude	90	60	30	0	30	60	90
Total solar radiation	0	34	107	161	174	151	124
Scattered back by air	0	7	14	20	20	21	15
Reflected by clouds	0	10	18	26	28	45	46
Reflected by ground	0	3	8	13	15	10	11
Absorbed by air	0	4	15	22	24	21	17
Absorbed by clouds	0	3	4	7	5	9	7
Absorbed by ground	0	7	48	73	82	45	28

breakdown for winter and summer half-years, at a number of latitudes. Cloud reflection and absorption estimates are the least certain of the various items tabulated.

Table II gives the energy budget of the earth's surface, with an approximate accounting of all forms of energy transfer. The net loss of terrestrial radiation is the balance between the upward flux of black-body radiation and the downward infra-red flux emitted by the atmosphere. The heat storage term, which includes phase changes of water substance, is positive for a ground cooling, since this process releases heat to the surface. The evaporation and oceanic transport terms are the most uncertain of the estimates in this table.

TABLE II

ENERGY BUDGET OF EARTH'S SURFACE, IN KLY (10^3CAL./CM.^{2}) PER HALF-YEAR

	Winter				Summer		
Latitude	90	60	30	0	30	60	90
Absorption of solar radiation	0	+7	+48	+73	+82	+45	+28
Net loss of terrestrial radiation	−18	−17	−27	−23	−27	−21	−21
Ground heat storage	+9	+10	+9	0	−9	−10	−9
Evaporative heat loss	−1	−6	−28	−45	−40	−12	−1
Convective heat loss	0	0	−3	−1	−3	−4	−4
Differential oceanic heat transport	+10	+6	+1	−4	−3	+2	+7

Table III gives the energy budget of the earth's atmosphere, again with an approximate accounting of all forms of energy transfer. There are considerable uncertainties in many estimates in this table, especially in the transport term.

TABLE III

ENERGY BUDGET OF ATMOSPHERE, IN KLY (10^3CAL./CM.^{2}) PER HALF-YEAR

	Winter				Summer		
Latitude	90	60	30	0	30	60	90
Absorption of solar radiation	0	+7	+19	+29	+29	+30	+24
Total loss of terrestrial radiation	−60	−59	−55	−52	−56	−59	−61
Atmospheric heat storage	+5	+2	+1	0	−1	−2	−5
Condensation heat gain	+3	+17	+26	+53	+27	+16	+5
Convective heat gain	0	0	+3	+1	+3	+4	+4
Differential atmospheric heat transport	+52	+33	+6	−31	−2	+11	+33

Over the year as a whole, the radiation balance of the earth plus atmosphere must equal zero when averaged over all latitudes on an areal basis, and must be balanced, over any latitude strip, by meridional differential transport processes, i.e., by the positive or negative accumula-

tion of heat resulting from latitudinal variations of the total poleward heat flux. Over shorter periods of time than a year, heat may be stored in the earth or atmosphere, as is shown in Table IV. The advective heat transport can take three forms—the advection of heat by ocean currents, the advection of real (or sensible) heat by the atmosphere and the advection of latent heat by the atmosphere. This latter is actually the water vapour advection required to balance evaporation, condensation and vapour storage. All three modes of differential heat transport are tabulated in Table IV.

TABLE IV

ENERGY BUDGET OF EARTH PLUS ATMOSPHERE, IN KLY PER HALF-YEAR

	Winter				Summer		
Latitude	90	60	30	0	30	60	90
Solar radiation gain	0	+14	+67	+102	+111	+75	+52
Terrestrial radiation loss	−78	−76	−82	−75	−83	−80	−82
Total heat storage	+14	+13	+11	0	−11	−13	−14
Heat transport by oceans	+10	+6	+1	−4	−3	+2	+7
Real heat transport by air	+52	+33	+6	−31	−2	+11	+33
Latent heat transport by air	+2	+10	−3	+8	−12	+5	+4

It can be appreciated that the radiation balance of the earth and atmosphere is related in a very complex manner to the general circulation of the atmosphere. The radiation balance defines the meridional heat exchange which the general circulation must deliver; in addition, the poleward temperature gradients resulting from the radiation source at low latitudes and the sink at high latitudes control the zonal intensity of the atmospheric wind fields. On the other hand the distribution of clouds and precipitation is associated with the evolution of synoptic weather patterns and thus with details of both the general circulation and the latent heat fluxes which the general circulation provides. The cloud distribution is the most important single factor controlling the radiation balance of the earth and of the atmosphere. Over periods of time shorter than a year there may be substantial storage of real and latent heat in specific latitude belts. The real heat storage affects the infra-red radiation streams through the temperature, and the latent heat storage through the water vapour content of the air, in addition to its effects on clouds and precipitation. Thus, the atmospheric general circulation, whose study is undoubtedly the most fundamental problem which meteorologists can tackle, is linked inextricably with radiation balances by mechanisms so complex that their elucidation with present observational tools is well-nigh impossible.

The chief reason for the fundamental importance of general circulation studies may be stated very simply. During the period of verification of a short-range forecast (one to two days,) the general circulation may be regarded as essentially a fixed parameter. For an extended-range forecast (three to ten days), changes in the general circulation are the primary elements to be forecast, after which synoptic weather events can be added rather simply as a result of the association between weather patterns and circulation patterns. In the case of a long-range forecast (for a month, season or year), the general circulation is once again the primary element to be assessed, but in this case its correlation with "present conditions", i.e., those at the time of issue of the forecast, is so poor that one must forecast a new state of the atmosphere rather than a changed or modified state (as is the case with extended-range forecasting). It is not surprising, then, that there are at present neither rational physical techniques nor adequate statistical techniques available for long-range forecast purposes.

When we progress to even longer time periods, we are in the domain of climatic change—ice ages and inter-glacial periods. Considerations of processes and mechanisms here are almost pure speculation, characterized by drastically divergent views. Yet the fact remains that the only fundamental difference between climatic change and extended-range forecasting is one of time scale; both depend primarily on the general circulation and on the manner in which it reacts to, and causes, a changing radiative balance.

Spectral Investigation of Solar and Atmospheric Radiation. The wave-length subdivision of radiative fluxes at outer space should assist greatly in the estimation of the separate radiation balances of the earth and atmosphere. In order to isolate relatively narrow regions of the spectrum, one can employ special detector-filter combinations. Thus, use could be made of near-infra-red albedos to assist in differentiating between clouds and snow, since the albedo of snow decreases rapidly with wave-length in the infra-red. Observations of scattered ultra-violet radiation at several wave-lengths can be interpreted to give a measure of the vertical distribution of ozone (Singer and Wentworth, 1957), since the ozone absorption coefficient (Hartley band) varies more rapidly with wave-length than does the molecular scattering coefficient. It might also be possible to use artificial radiations (10 cm. radar for precipitation and 1 cm. radar for clouds) to obtain further information on weather elements. Such data would be available for any area at roughly 12-hour

intervals, which would be ideal for the portrayal of the motion of synoptic features.

Spectral studies of emitted radiation are capable, in theory at least, of yielding information on atmospheric temperatures and on concentrations of infra-red absorbents. In relatively transparent spectral regions ("atmospheric windows") the emitted energy is a measure chiefly of the ground or cloud top temperature; in the latter case, a further technique for 12-hour motions is thereby available. In the vicinity of band centres, the emitted intensity will vary chiefly with the temperature and concentration in the uppermost layer of large absorption. Such information could be obtainable from the 6.27 micron band of water vapour, the 9.6 micron band of ozone and the 15 micron band of carbon dioxide.

Meteorological Implications of Geophysical Experiments. One of the chief geophysical experiments as planned for the U.S. satellite programme (Newell, 1957) is the detection of solar Lyman-alpha radiation. This radiation comes from a hydrogen emission line at 1216 A., which is very narrow and very intense. It will be measured by an ionization chamber detector sensitive over the range 1100–1300 A., in which range Lyman-alpha supplies 95 per cent. of the solar energy. Two magnetic cores will be employed, in rotation, one storing information during an orbit and the other modulating the Minitrack transmitter. This short ultra-violet radiation is completely absorbed in the ionosphere and undoubtedly undergoes large variations during solar flares. Although this radiation is not directly available to the lower atmosphere, it may still exert an indirect influence there, as has been suggested by Willett (1953) and Bell (1953).

A second basic geophysical experiment is the measurement of cosmic rays, with a Geiger counter. The total incidence of cosmic rays, without regard to charge, energy or direction, will be stored on a magnetic tape recorder and this information telemetered on command. Since primary cosmic rays are probably corpuscular in nature (protons, etc.), additional knowledge will be obtained concerning background solar emission of this type and the additional fluxes which follow solar storms. This will be of particular interest to meteorologists in view of the theory of Menzel (1953) that predicts a local ionic flux, presumably in auroral zones, of the same order as the solar constant, as a result of a funnelling or focusing effect by the earth's magnetic field.

This latter thesis may also be examined more critically using the results from a third basic geophysical experiment, the measurement of

the total magnetic field of the earth (scalar only) using a proton-precessional magnetometer. These data are also expected to confirm or refute the existence of an equatorial ring current well beyond the earth's outer atmosphere.

Of the supplementary and environmental studies planned for the U.S. satellites, the one of chief interest to meteorologists will be the detection of micrometeorites. This can be done with microphones inside the outer shell of the satellite which will record the impact-noise of micrometeorites. These impacts can be counted and the rate telemetered to earth. As suggested by Ovenden (1956) and others, such data will permit a quantitative assessment of the controversial hypothesis of Bowen (1953) that meteor showers result in a global increase in precipitation (with a lag of 30 days) as a result of the ice-nucleating properties of such particles.

Conclusions. Whatever developments may occur in satellite instrumentation or in techniques for the processing and analysing of satellite data, one fact appears to be self-evident: satellites have a tremendous potential value for the science and practice of meteorology. It will undoubtedly demand inspiration, opportunism and a prodigous developmental programme in order to make efficient use of satellite data, but the advantages are so apparent that anything less than a maximum effort toward such a goal would be most unfortunate. eLt us hope that the effort expended in launching satellites can be matched by those entrusted with the task of turning the hard-won information about the atmosphere to practical use.

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VISUAL OBSERVATIONS OF ARTIFICIAL SATELLITES

By John F. Heard

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Those who have not given very much thought to the motions of the satellites are often confused by the predictions and reports concerning visual sightings. This note is an attempt to clear the matter up.

Before we consider the factors which make a satellite visible at some times and not at others, let us consider how a satellite moves over the earth's surface. We must realize that the orbit of a satellite is *nearly* fixed in space, but not quite; due to the gravitational influence of the earth's equatorial bulge, the orbit precesses slowly about the earth's axis. The direction of this motion is westward for a satellite moving in a direct orbit. But for the moment let us ignore this precession and think of the orbit plane as fixed in direction; that is, it remains, let us say, parallel to itself regardless of the rotation and revolution of the earth.

The first two Russian satellites were inclined to the earth's axis by about 25 degrees. Thus we can see that the earth's rotation will carry any specified place, provided it is more than 25 degrees from the pole, under the orbit twice in every sidereal day (23 hours and 56 minutes of solar time). The intervals between these passages under the orbit will not be the same except at the equator. For example, at latitude 45 degrees, the intervals are alternately about 8 hours and 16 hours.

Now let us think about the satellite's motion on the orbit, supposing that we know its period. For satellite 1957β (Sputnik II) in mid-January of this year, the period of revolution was 99.3 minutes. This means that 14 revolutions are completed in 23 hours and 10 minutes. Now suppose that the satellite has passed south-eastward over the 40th parallel of latitude at longitude 71.7 degrees west at 19:27 E.S.T. on January 20 (as in fact it did). Now, skipping over the passage towards the north-east which will occur nearly sixteen hours later over the same locality, let us concentrate our attention on the next evening's south-eastward passage over the same locality. After fourteen circuits just 23 hours and 10 minutes have elapsed, so that the earth lacks 46 minutes of having completed a rotation. This corresponds to 11.5 degrees of longitude. Thus the satellite might be expected to be 11.5 degrees farther east when it crosses the 40th parallel, that is at longitude 60.2 degrees west. This crossing will take place at 18:37 on January 21. However, let us re-

member now the three degrees by which the satellite orbit precesses westward each day. Applying this correction, we predict the longitude of the crossing of the 40th parallel to be 63.2 degrees west.

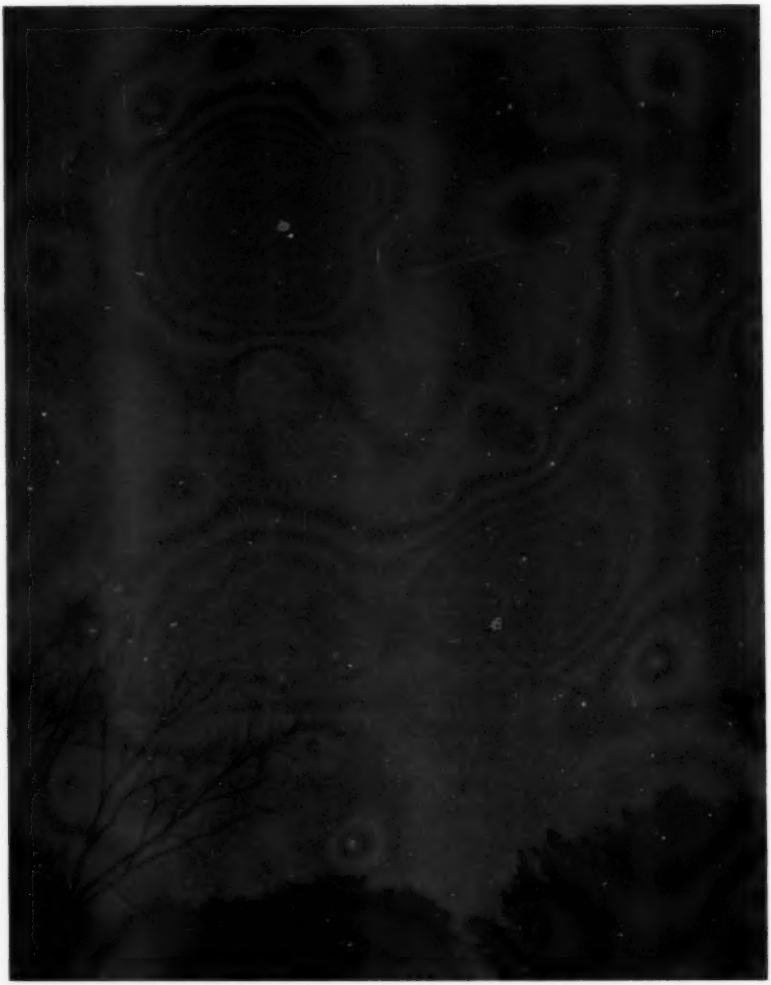
The question which we have not dealt with yet is whether or not these passages might be seen. To be seen, the satellite must be in the sunlight while the sun is below the observer's horizon, and also, needless to say, the satellite must not be so far away as to be below the observer's horizon. That is to say, the satellite must pass nearly over our locality just after sunset or just before sunrise. Just how "nearly over" and within what time of sunrise or sunset—these depend on the height of the satellite at that passage; but as a general working rule for the first two sputniks, one could expect to see the satellite if it passed within a few degrees of our longitude within about two hours of sunset or sunrise. The higher the satellite, the greater the range of both times and longitudes; also, if we visualize the shadow of the earth slanting upwards, we will realize that the more favourable situations will occur with the satellite passing to the sunward side of our locality, that is, to the west in the evening twilight and to the east in the morning.

On both days referred to in the foregoing example, the satellite was visible in the eastern part of North America at and near the 40th parallel. On each day, the next passage, occurring about 25 degrees farther west and an hour and forty minutes later, was likewise visible in the central part of the continent, sunset being correspondingly later there—and so forth, all the way around the globe. It is thus the latitude which primarily governs the visibility of a satellite. In fact, when the twilight circle cuts the satellite orbit near our latitude we have a chance of seeing it.

From these remarks it should be clear that it is not possible to make exact predictions of times of sightings to be expected over wide areas; a prediction valid for Toronto may not be valid for Ottawa, let alone Edmonton. The Smithsonian Astrophysical Observatory in Cambridge, Mass., has been making its day-to-day forecasts of positions available to the larger observatories in the form of times and longitudes of crossings of the 40th parallel. The observatories can then interpret these data for local groups which are interested in making observations. The time factor is a limitation, however, since the orbit requires constant revisions, and therefore accurate predictions valid for more than a few days are impracticable. On the other hand, the general pattern of periods of visibility can be forecast reasonably well if the rate of change of the period is known. The pattern has been rather interesting. Broadly speaking, for a given latitude there are periods of visibility lasting for some days, which recur every few weeks in the sequence: morning, morning,

evening, evening, etc. A set of morning observations of the rocket carrier of the first sputnik seen in the Toronto and Ottawa regions between October 13 and 16 illustrated the precession of the orbit very neatly. It happened at this time that the period of the rocket was 95.7 minutes and thus 15 circuits were completed in almost exactly 23 hours and 56 minutes. This meant that apart from a precessional movement of the orbit itself, a given observer would have expected to see the passages on successive mornings in exactly the same position among the stars. In fact, however, the successive passages worked their way towards the west. Thus it was possible to compute very simply the rate of precession; it turned out to be about 3¼ degrees per day as referred to the earth's axis, confirming approximately the rate computed in the accompanying note by Dr. Searle.

Many Canadian groups made visual sightings of the rocket of the first satellite and of the second satellite. At the Dominion Observatory at Ottawa, an excellent scheme was used for obtaining accurate times to go with visually estimated positions; this involved the use of a tape recorder which was recording radio time signals along with brief comments by the observers. The same scheme was used by observers of the Montreal Centre of the Society. What was believed to be the first photograph of a satellite on this continent was taken at the meteor observing station of the Dominion Observatory at Newbrook, Alta., on October 9. Other excellent photographs were taken at the Dominion Astrophysical Observatory and the David Dunlap Observatory. Good photographs can be made very simply by using a 35-mm. camera mounted on a tripod and pointed ahead of the satellite; an exposure of 15 seconds or more will record the star positions, and if the lens is covered momentarily at a recorded time, the photograph, showing a break in the trail, has considerable value for determining the exact position. Many observers commented on the marked changes of brightness during the passages, caused presumably by the toppling of these cylindrical objects in the course of their flight. The satellite itself of the first launching was not seen with certainty by Canadian observers as far as the writer knows.



Photograph of the trail of the launching rocket of the first Russian satellite (1957 α_1), taken by Peter M. Millman in Windsor Park, Ottawa, on the morning of October 13, 1957 at 5h 13m 50s E.S.T. Duration of exposure: 43 seconds.

SATELLITE PERIODS AND VELOCITIES

By Peter M. Millman

National Research Council

During recent months many numerical inconsistencies have appeared in news items relating to earth satellites. In particular, statements about satellite speeds, and the corresponding heights above the earth's surface, have been generally unreliable. The theory giving the relations among the height, velocity and period of a small earth satellite is straightforward and not difficult. I will summarize here some basic concepts as a guide to readers of the Journal who may wish to follow future satellite launchings.

We can start with a fundamental equation in celestial mechanics which applies to the motion of one mass moving in a Newtonian orbit relative to a second mass:

$$V^2 = G(M+m)\left(\frac{2}{r} - \frac{1}{a}\right), \tag{1}$$

where V is relative velocity, G the constant of gravity, M and m are the two masses, r is the distance between the masses, and a is the semi-major axis of the relative orbit. In the case of a small earth satellite its mass can be considered negligible compared to the mass of the earth. If R is the earth's radius at some point and H the height of the satellite above the earth's surface at this point, then $r = R + H$ and equation (1) becomes:

$$V^2 = GM\left(\frac{2}{R+H} - \frac{1}{a}\right). \tag{2}$$

In the case of a circular orbit H remains essentially constant, H_o, say, and $r = a = \mathrm{R} + \mathrm{H}_0$. Equation (2) becomes:

$$V^2 = \frac{GM}{R+H_0}. \tag{3}$$

The period in a circular orbit is given by:

$$P = \frac{2\pi(R+H_0)}{V}. \tag{4}$$

Using constants as given by Allen (1955), we have:

$GM = 95{,}637$ miles^3 sec.$^{-2}$

R (at lat. 45°) $= 3956.7$ miles.

For various values of H_0, at 45° latitude, we can compute the corresponding V and P for satellites moving in circular orbits. Typical examples are listed in the table and plotted in figure 1. Intermediate values can be found by interpolation.

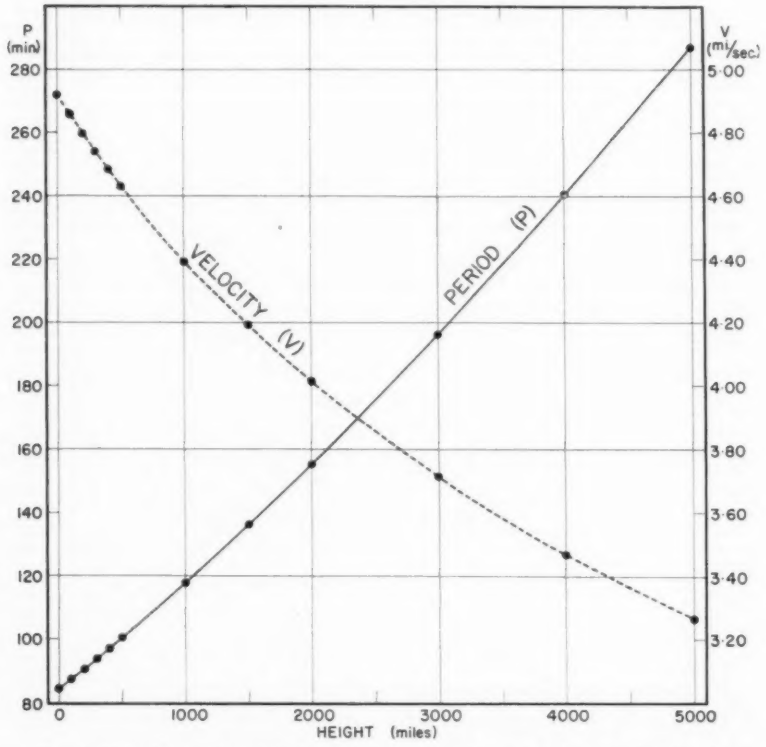


FIG. 1—Velocities and periods for circular orbits, shown in relation to height above the earth's surface.

The approximate period is one of the first elements available when a new satellite is launched, and the average height and velocity can be found quickly from the above table. If the satellite is moving in an elliptical orbit, as is likely, then at apogee it will be some distance, h, say, above the average height, and at perigee it will be lower than the average height by the same amount. It will have a maximum height

of $H_0 + h$ and a minimum height of $H_0 - h$. The eccentricity of the orbit will be:

$$e = \frac{h}{R+H_0}. \tag{5}$$

VELOCITIES AND PERIODS FOR CIRCULAR ORBITS

H_0 (miles)	V (miles/sec.)	P (minutes)	H_0 (miles)	V (miles/sec.)	P (minutes)
0	4.92	84.3	1,000	4.39	118.2
100	4.86	87.5	1,500	4.19	136.5
200	4.80	90.7	2,000	4.01	155.7
300	4.74	94.0	3,000	3.71	196.5
400	4.69	97.4	4,000	3.47	240.3
500	4.63	100.7	5,000	3.27	287.0

Davis, Whipple and Zirker (1956) have shown that the positions of the ascending node and the line of apsides will precess as a result of the oblateness of the earth. Atmospheric drag will alter the semi-major axis and eccentricity.

It is important to note that the velocity of a satellite at a given height above the earth's surface will depend on the orbital semi-major axis, a, eccentricity, e, and the position of the satellite relative to the perigee point. For example, in figure 2, consider a satellite at point A, 2,000 miles

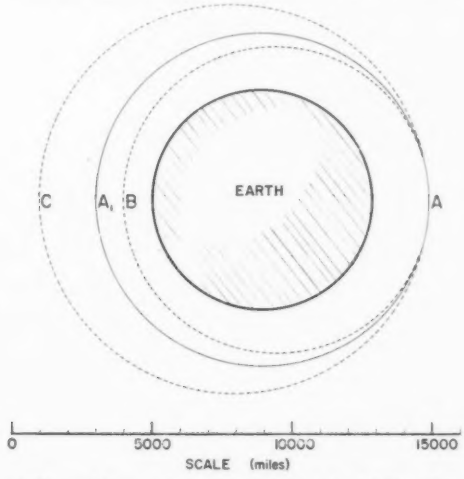


FIG. 2—Three satellite orbits passing through point A, 2,000 miles above the earth's surface.

above the earth's surface. If motion is in the circular orbit AA_1 ($a = R + 2{,}000$; $e = 0.0$), the velocity at A, and over all the orbit, will be 4.01 miles/sec. If, however, the satellite is moving in the elliptical orbit AB ($a = R + 1{,}500$; $e = 0.09$), the velocity at A will be 3.82 miles/sec., at B 4.59 miles/sec., with an average velocity in the orbit of 4.19 miles/sec., corresponding to the smaller a. Though the mean velocity is higher, the speed at A is smaller than before. On the other hand, if the satellite is moving in the orbit AC ($a = R + 3{,}000$; $e = 0.14$), velocity at A is 4.28 miles/sec., at C 3.20 miles/sec., and the average velocity is 3.71 miles/sec.

In any orbit the centrifugal force varies with the square of V. Any drag, that is atmospheric resistance to the satellite's motion, will tend to reduce the centrifugal force and the earth's gravity will then pull the satellite in along a path which will spiral down inside the drag-free orbit. The effective a's will be smaller than before and the resulting average velocities in each revolution will be higher. As has been pointed out in a number of recent papers, though the drag is strongest at perigee, the most significant change in the orbit will be the reduction of the apogee distance of the satellite, while the perigee distance remains relatively unchanged. This will result in a lower eccentricity. Just how high a satellite must revolve before the atmospheric drag becomes unimportant is one of the questions to be answered by the observations of satellites.

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THE PERTURBATIONS OF AN EARTH SATELLITE

By Leonard Searle

David Dunlap Observatory, Richmond Hill

If a satellite were orbiting a hypothetical planet, supposed to have no atmosphere and to possess spherical symmetry, and if no other perturbing bodies were present, then the orbit would be an ellipse fixed in space relative to the stars, and the earth's centre would be at one of its foci. The period of such a satellite would be constant. In the real situation of the earth satellites, the perturbing effects of the earth's non-spherical shape and of the atmosphere cause the actual orbit to be much more complicated, but we can still describe the orbit as an ellipse whose size, shape and orientation are slowly changing.

A prediction of the passage of a satellite over a particular location on the earth, based on a previous sighting generally requires some knowledge of these changes. An amateur observer is most likely to be concerned with the precession of the orbital plane and the decrease in period. It is the purpose of this note to give an elementary account of these phenomena.

The precession of the orbital plane. To make the discussion simple, consider a satellite with period P moving in a circular orbit of radius a about the earth. The oblateness of the earth gives rise to forces which tend to pull the satellite plane into the earth's equatorial plane, but the orbiting satellite is a gyrostat so that it reacts to these forces as does a top in similar circumstances—it precesses.

The precessional angular velocity ω is determined by the torque T acting on the gyrostat and the angular momentum μ of the satellite about the earth's polar axis. These quantities are related by the formula

$$\omega = T/\mu. \tag{1}$$

The torque can be evaluated once we know the potential due to the oblate earth. This is approximately

$$\Psi = -\frac{GM}{r}\left[1 + k\left(\frac{1}{r^2} - \frac{3z^2}{r^4}\right)\right], \tag{2}$$

where Ψ is the potential evaluated at a distance r from the earth centre and at a distance z above the earth's equatorial plane, M is the mass of

the earth and G the constant of gravitation. k is a constant characterizing the earth's deviation from spherical symmetry.
A little computation then yields

$$\omega = \Gamma(a)\, n \cos i, \tag{3}$$

where

$$\Gamma(r) = \frac{3k}{r^2}, \tag{4}$$

and $n = 2\pi/P$ is the angular velocity of the satellite in its orbit and i is the inclination of the orbital plane to the equator. Gravity studies and observations of the moon give

$$\Gamma(R) = 1.64 \times 10^{-3}, \tag{5}$$

where R is the radius of the earth. Using this figure we obtain

$$\omega(\text{degrees/day}) = 10 \times (\mathrm{P_0/P})^{7/3} \cos i, \tag{6}$$

where P_0 is the orbital period of a satellite travelling around the earth at its surface, about 85 minutes. Notice that the longer the period of the satellite (i.e. the greater its mean height), the slower is the precession; also the precession is greatest for a satellite orbit only slightly inclined to the earth's equator and vanishes entirely for one passing over its poles.

As an example, for a satellite with a period of 96 minutes and an inclination of 65°, the intersection of the orbit and equator (i.e. the node) regresses along the equator ω degrees per day where ω is given by equation (6) as 3°.2.

If ω is measured very accurately then a more accurate expression for Ψ than has been used in this discussion can be derived. In other words, accurate observations of the precession will yield information about the mass distribution within the earth.

The change of period. The effect of atmospheric resistance on the motion of a satellite in a circular orbit is to cause the satellite to fall toward the earth and speed up. The period of the satellite decreases.

It is sometimes propounded as a paradox that the atmospheric resistance can result in an increase in the speed of a satellite. The matter can perhaps be most easily understood this way. Per unit mass the satellite has kinetic energy $T = \frac{1}{2}v^2$ and potential energy $\Psi = -GM/a$. The total energy $E = T + \Psi$ would be constant if there were no atmospheric resistance.

The stability of a circular orbit is guaranteed by the equality of the gravitational acceleration acting inward and the centrifugal acceleration acting outward. This condition can be expressed by the equation

$$2T + \Psi = 0. \tag{7}$$

A satellite moving in a resisting atmosphere experiences a retarding acceleration F and in moving a distance ds does work equal to Fds and must lose that amount of energy.
So

$$dE/dt = -F.v. \tag{8}$$

The effect of atmospheric resistance then, is to reduce the total energy $E = T + \Psi$ but the orbit is continuously adjusted so that the stability equation (7) remains valid. Obviously this implies that T increases with time while Ψ decreases. In other words, the speed v continuously increases while a decreases. From equation (8) it can easily be shown that

$$\frac{da}{dt} = \frac{2F}{n}. \tag{9}$$

From the observed changes in the orbit the resisting acceleration F, and hence the density of the upper atmosphere can be calculated. That is, of course, one of the principal reasons that the satellites are up there.

RESEARCH AT THE MOUNT STROMLO OBSERVATORY*

By William Buscombe

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About five years ago there appeared in this Journal an outline of the historical development of optical observatories in Australia (Hogg, 1953), which was followed by an account of the research in radio astronomy carried out at the Radiophysics Laboratory in Sydney (Pawsey, 1953). Although the importance of studying the southern sky from Australia has been realised for generations, many vicissitudes have delayed the assembling of equipment adequate for the task.

The original equipment of the Commonwealth Observatory on Mount Stromlo was a large tower telescope which filled an important gap in the world-wide network for continuous observation of the sun. The precise work of C. W. Allen established a standard for the photometry of Fraunhofer absorption lines on photographs of the solar spectrum with high dispersion. In the decade before the outbreak of the Second World War many measurements were performed on solar radiation, cosmic rays and atmospheric electricity. In addition to the detailed optical studies of the sun, daily measures of solar radio noise at 200 mc./s. were made for several years. The same receiver was later used by Allen and Gum for a survey of the radio-frequency radiation from the galaxy.

The analysis of records of the reflection of radio waves (of terrestrial origin) from the upper layers of the earth's atmosphere led during the war to the establishment of the Ionospheric Prediction Service for improving the reliability of international radio communications to and from Australia. Although the computing and editorial headquarters of the Service has been in Sydney for many years, the administrative direction became separated from the Observatory only after June 1956, so that it remains a section of the Department of the Interior. Later in the year, after the passage of an Act of Parliament, the control of the Observatory's Time Service and astrophysical work passed from the Department of the Interior of the Commonwealth Government to the Research School of Physical Sciences of the Australian National University.

During the war, the Observatory became a small factory for the design and manufacture of fire-control equipment and the optical components

*Mount Stromlo Observatory Reprints No. 6.

of military instruments. The workshop was enlarged to accommodate a wide range of machine tools, and staff members gained valuable experience in instrument design and construction. As the demand for munitions decreased, it became possible to devote attention to mechanical and optical modifications of the 50-, 30-, and 20-inch reflectors under the direction of K. Gottlieb, design engineer.

D. G. Thomas, who established the communications facilities and relays for the quartz crystal oscillators for the National Time Service during 1948–49, later designed and built the electrical frequency control equipment for driving the telescopes, and a considerable array of photoelectric photometers and amplifiers. After the disastrous bush fire of February 1952 (Eggen, 1952) a very determined effort was made to rebuild the machine shop and provide a range of modern machine tools with which large and small instrument construction and maintenance are carried out by H. J. Banham and a team of craftsmen. At the time of writing a large extension is about to be erected to house the optical, electronic and photographic laboratories which have outgrown the space available in the central quadrangle of office buildings.

An outline of the work completed and in progress will show the wide range of interests being pursued with the very diversified equipment. The principal telescopes are listed in the table.

TELESCOPES OF THE MOUNT STROMLO OBSERVATORY

Type	Aperture	Focal Ratio	Type of Mounting	Remarks
	inches			
Reflector	74	Newtonian f/5 Cassegrain f/18 Coudé f/30	Equatorial, English	Built by Grubb Parsons
Reflector	50	Gregorian f/18	Equatorial, English	Great Melbourne Telescope
Reflector	30	Newtonian f/4 Cassegrain f/18	Equatorial, Fork	Reynolds
Reflector	20	Cassegrain f/18	Equatorial, German	Catts
Reflector	12	f/43	Coelostat	Solar Tower
Refractor	6	f/12	Equatorial, German	Farnham
Meinel-Pearson Schmidt Camera	12 8-in. correcting plate	f/1	Mounted on Farnham Telescope	
Refractor	9	f/15	Equatorial, German	Oddie
Zeiss Camera	5	f/5	Mounted on Oddie Telescope	
Refractor	3¼	f/12	Meridian	Transit
Refractor	10	f/13.5	Photographic Zenith Tube	
Refractor	26	f/16	Equatorial, English	Yale-Columbia
Schmidt	26 20-in. correcting plate	f/3.5	Equatorial, English	Uppsala

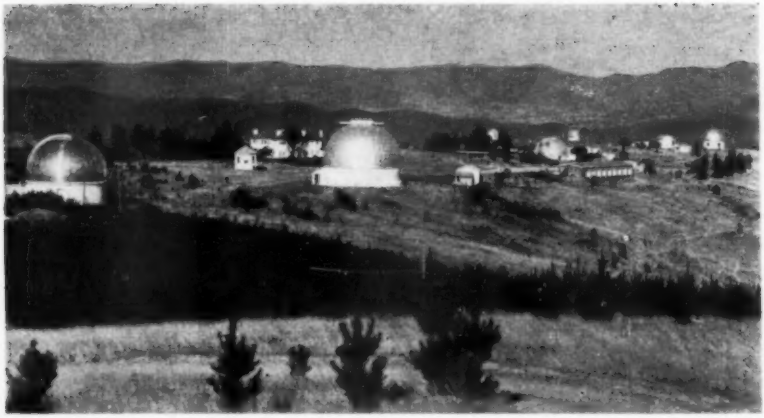

FIG. 1—Skyline of Mount Stromlo, taken from the Oddie dome looking south toward the Australian Alps. From east to west, *foreground*: Yale-Columbia refractor, kite house (formerly for cosmic ray studies), 74-inch reflector, optical shop, new machine shop, 20-inch and 30-inch reflectors. *Background*: Director's residence, Uppsala Schmidt, solar tower, 50-inch reflector, Farnham dome on top of offices, transit, P.Z.T. with separate Control Hut.

Photometry. Photometric studies have received an increasing amount of attention in recent years. Using the technique of monochromatic photographic magnitudes pioneered by R. v.d. R. Woolley, S. C. B. Gascoigne determined the colour gradients of 166 southern stars from measurements of the photographic density on slitless spectograms exposed with the 30-inch Reynolds telescope, and also the apparent stellar magnitude of the sun, by comparison with Sirius. By means of observations with a photoelectric photometer, A. R. Hogg established that light curves and orbital elements of two eclipsing binaries, S Antliae and Zeta Phoenicis, while Gum first detected the light variation of small amplitude and derived the absolute dimensions of the system IM Monocerotis. At present F. B. Wood of the University of Pennsylvania is determining the light curves of several eclipsing binaries photoelectrically at Mount Stromlo.

When more powerful telescopes came into use after 1948, the research interests of the Observatory staff spread to the study of fainter and, in general, more distant objects related to the structure of the Milky Way system, the Magellanic Clouds and other external galaxies. Although the central bulge and inner spiral arms of the Milky Way are visible only at a low elevation for a short time near the southern horizon from

Europe and North America, these important regions dominate the sky all through the winter nights in the southern hemisphere. Observatories in Argentina, South Africa and Australia are favourably located for the study of these features of the southern sky. Since Mount Stromlo is the world's southernmost active observatory, the convenience of observing the Magellanic Clouds at a high elevation is a unique advantage.

The two Magellanic Clouds are at only one-tenth the distance which separates the solar neighbourhood of our Milky Way from the nearest normal spiral galaxy M31 in Andromeda. Consequently it is possible with the moderately large reflectors on Mount Stromlo to study in similar details any objects in the Clouds which are intrinsically two magnitudes less luminous than the faintest ones in M31 which are accessible to the largest telescopes in California.

In collaboration with G. E. Kron of the University of California, who visited Mount Stromlo in 1951, Gascoigne showed that Cepheids and globular clusters in the Magellanic Clouds are bluer than the corresponding objects in the Galaxy, and apparently less luminous. The latter anomaly was adjusted by the adoption in the following year of a more expanded distance scale for extra-galactic objects. It is now believed that the Magellanic Clouds are some 150,000 light-years from the solar neighbourhood of the Milky Way system. Another visitor from the Lick Observatory, O. J. Eggen, obtained observations for a colour-magnitude array of southern as well as northern stars in the solar neighbourhood, and discovered the variable star SX Phoenicis, whose period of only 80 minutes is the shortest known.

At the present time Gascoigne is preparing colour-magnitude arrays for the globular clusters Omega Centauri, NGC 6397 and 47 Tucanae, and obtaining photoelectric light curves for a few variables in the Small Cloud. In addition he is searching the clusters in the Cloud as well as some of the southern globulars for variable stars. Hogg has completed three-colour photometry of some 250 bright southern stars to extend the array of standards for photoelectric work. Following a two-colour study of NGC 6025, he is obtaining measures on stars in a number of other galactic clusters. To standardize the magnitude scales for faint stars, observers measure comparison stars in internationally selected regions of the sky.

One of the first interests of G. de Vaucouleurs in coming to Mount Stromlo was to photograph the bright extragalactic nebulae of the southern sky. This was systematically done, mainly with the 30-inch reflector at the Newtonian focus, and later with the 74-inch telescope when available. From this material he developed a system of classification

along independent lines very similar to the one on which the late E. P. Hubble had been working at Mount Wilson up to the time of his death. Related work included the star counts and structural studies of the Magellanic Clouds, now considered as defective open spirals, and evidence for bridges of luminous intergalactic matter extending toward the Milky Way. Using the emission profiles of the 21-cm. hydrogen line observed at the Radiophysics Laboratory in Sydney, de Vaucouleurs, in collaboration with F. J. Kerr, succeeded in demonstrating for the first time that the two Magellanic Clouds are in rotation, and in deriving estimates of their masses and the proportions of gaseous interstellar matter.

An extended study of emission nebulae (glowing clouds of ionized hydrogen gas) in the southern Milky Way was made by Gum. At first these were observed with a nebular spectrograph built at the Observatory, which, however, was destroyed in the 1952 bush fire. Later, direct photographs, taken with a 4-inch Schmidt camera of very short focal length through various filter combinations, were compared to distinguish 85 regions, showing emission in the scarlet Hα line. He recently completed a catalogue of HII regions in a band straddling the section of the Galactic equator which had been omitted in surveys made from northern latitudes. In addition to establishing a system of classification Gum used this material to discuss evidence for spiral structure at distances as great as 2,000 parsecs from the sun. These regions are being studied for radio emission with receivers at Sydney, and the spectra of the exciting stars are being classified at Mount Stromlo.

A. W. Rodgers has been investigating the density and extent of the "Coal Sack" dark cloud near the Southern Cross, by measuring the change in colour caused in the light of background stars shining through the nebula. By combining photometric techniques with direct photographs and photoelectric recordings, B. J. Bok is making similar very detailed studies of the complex distribution of interstellar obscuring matter in the dense star clouds of the constellations Carina and Sagittarius in the Milky Way. He is also taking a leading part in attempts to identify with optical objects some of the cosmic radio sources which have been detected with directional antennae at Sydney. An 8-inch Schmidt camera, built to a design of A. B. Meinel in the United States, is now being mounted on the Farnham reflector to serve in studies of extended emission nebulae by Bok, Gum and Rodgers.

From examination of photographs of regions in the Milky Way, Magellanic Clouds and other southern galaxies Gum and de Vaucouleurs concluded that distinct groups of emission nebulae in annular form all have linear diameters of about 90 parsecs and may be useful as distance

indicators for the external galaxies in which they are detected. Other studies showed that observations of the brightness of distant novae may serve a similar purpose, provided that either the rate of fading from maximum through three magnitudes, or the apparent brightness at 15 days after maximum, can be accurately determined. While the principle is not original, the detailed comparison of similar groups of novae at known distances in the Milky Way and in an external galaxy (the Large Magellanic Cloud) was exactly carried out for the first time by de Vaucouleurs and Buscombe.

Although in general few observations of objects in the solar system have been made, several staff members exerted a special effort to use the favourable oppositions of Mars in 1954 and especially in 1956 (when the planet was too far south for accurate studies from northern observatories) to secure significant colour measures and data on surface markings. Several bright comets have been photographed when accessible, including 1948l and 1956h (Arend-Roland), for structural analysis and position measurement. A. Przybylski has computed the orbits of several other comets from world-wide observations.

Spectroscopy. The earliest work in stellar astronomy completed at Mount Stromlo was a series of 2,000 objective-prism spectrograms exposed with the 9-inch Oddie refractor by the late W. B. Rimmer. In an early *Memoir*, Rimmer discussed the parallaxes of the hot B-type stars derived from classification of these spectrograms. More recently Mary Lee Woods applied the temperature-luminosity system of spectral classification, which had been formulated by W. W. Morgan and his associates at the Yerkes Observatory, for the first time to a systematic survey of all bright southern stars.

Using materials partly assembled before his arrival, H. Gollnow took charge of the completion of a three-prism slit spectrograph which was brought into regular use in 1953. Over 2,500 spectrograms have been exposed during the first four years, with light fed to the instrument from the Cassegrain focus of the Reynolds 30-inch reflector. The prismatic camera is well insulated, and electrically heated at all times to maintain a constant temperature of 30°C. for uniform optical performance. The majority of plates intended for measurements of radial velocities have recorded the spectra of early-type stars in the region of the Scorpio-Centaurus cluster, and of other bright stars in the FK3 and N30 catalogues.

The first star of variable velocity which was intensively studied is Zeta Phoenicis, whose light variation had first been detected here a few

years previously. About fifty spectrograms have been measures by G. Hagemann, who is computing the spectrographic orbit. In a similar way Buscombe has derived the orbital elements for the spectroscopic binary Delta[2] Telescopii and is proceeding with several others related to the larger radial-velocity programmes. Collaborating with Hogg to secure simultaneous spectrographic and photometric observations, Gollnow has made intensive studies of the rapidly pulsating stars Sigma Scorpii and Beta Crucis on many nights. Buscombe has contributed velocity measures of Theta Ophiuchi to co-operative study with A. van Hoof of Louvain and other observers in Canada, South Africa, Argentina and the United States.

During a visit from Harvard College Observatory S. Gaposchkin used the spectrograph to observe several southern Cepheids and other stars with expanding envelopes to study the velocity variations and especially the behaviour of emission lines. Buscombe has also studied the very bright Cepheid Rho Puppis through several three-hour cycles. From the combination of new velocity measurements with a number of old results previously published on a single curve it was possible to derive a very exact period. Also it was found that Rho Puppis exhibits phase shifts in the velocities of different atmospheric layers, somewhat similar to those in Cepheids of much longer period.

By comparing the spectra of programme stars with those of bright stars in the equatorial zone which had already been chosen as standards of spectral type by Morgan, Mrs. A. de Vaucouleurs extended the luminosity classification to many fainter southern stars. By adopting the absolute magnitude scale for B stars, she derived an average distance of 220 parsecs for members of the Scorpio-Centaurus cluster, in satisfactory agreement with the results of recent determinations of the proper motions of the stars. A special effort is being made, by agreement with other southern observers, to select suitable additional standards for spectral type to replace far northern members of Morgan's list. This work is being continued under the direction of Buscombe by Miss P. M. Morris, and extended to the study of spectrograms taken with the Zeiss two-prism spectrograph at the Newtonian focus of the 74-inch reflector. While the basic optical arrangement of this instrument gives a dispersion of 100 A./mm. at $H\gamma$ (which is particularly suited to this type of study), a change to a pair of ultra-violet prisms giving 140 A./mm. is easily made. By the use of a camera lens of shorter focal length, spectra of fainter objects may be secured with dispersions of 200 or 290 A./mm. respectively.

The Newtonian spectrograph is proving especially suitable for the

exploration of the spectra of southern stars for the presence of interstellar absorption lines, whose structure may be investigated in greater detail when a grating spectrograph of high dispersion becomes available. Plans for such an instrument at the coudé focus of the 74-inch telescope are well advanced, and the actual erection will proceed as soon as T. Dunham, Jr. has assembled the optical components on Mount Stromlo to

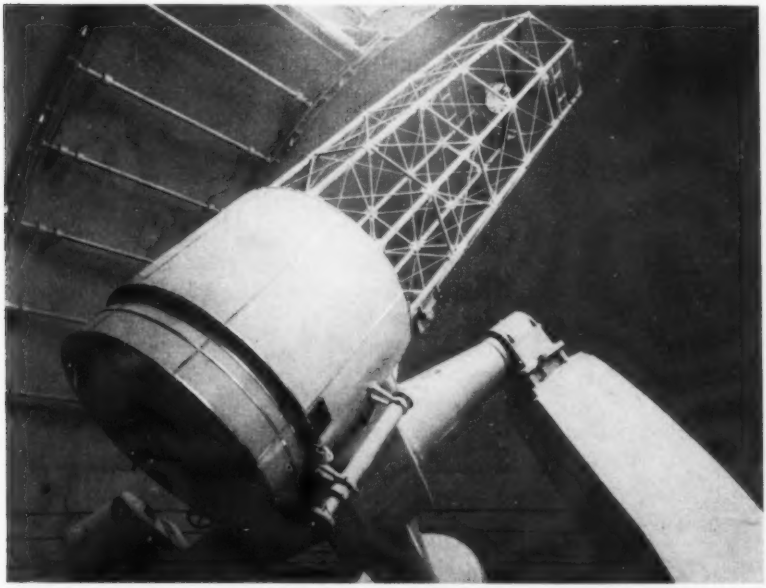

FIG. 2—The 74-inch reflector, built by Grubb, Parsons.

serve for both photoelectric and photographic spectrophotometry. Observations already in progress by these techniques will contribute to the study of many types of object represented by bright southern specimens, and also to an improved determination of spectroscopic parallaxes. When a secure foundation has been laid for radial-velocity work with lower dispersion, such objects as faint planetary nebulae and high-velocity stars hitherto neglected in the southern hemisphere will take their place on the observing lists.

Joint studies including spectrographic observations for classification and the measurement of radial velocities are being made in connection with Hogg's work in the photoelectric photometry of open galactic

clusters. In addition to the extension of investigations of the comparatively near but widespread association of B stars in the Scorpio and Centaurus region (in which observing is shared with the Radcliffe and MacDonald observatories), work is already in hand on several more distant clusters in the farther background along the galactic plane, including NGC 4755 (Kappa Crucis) and IC 2602 (Theta Carinae). While adding new information related to the evolutionary history of star groups, the combination of the data in colour-magnitude arrays with kinematical studies of the group motions also leads to more precise knowledge of the distances and intrinsic luminosities of the types of stars which are members.

Astrometry. The National Time Service was established in 1944 to take over the work when the State Observatory in Melbourne was closed, and is under the direction of H. J. M. Abraham. Several years ago G. Simonow completed an extensive revision of the manuscript catalogues of stellar positions formerly observed at Melbourne, which are now available in microfilm form on special request. In keeping with the reliability of the set of clocks controlled by quartz oscillators, a photographic zenith tube has recently been installed with which more precise determinations of astronomical time can be made than through visual meridian transit observations. Although the P.Z.T. (like the one in Ottawa, for example) can record transits only of stars within 15′ of the zenith, its 10-inch objective lens permits the selection of much fainter stars than those observed visually with the 3¼-inch transit circle. The reduction of time observations has for several years been conducted mainly by Mrs. C. Wehner. During the International Geophysical Year, special co-operative efforts are being made to study the complex motion of the earth's pole of rotation and to tie together the geodetic surveys of the five continents. During the transit of Mercury on 1957 May 6, a series of photographs taken with the solar tower telescope recorded the path of the planet across the solar disk. In addition, a dual-rate Moon Camera, designed by W. Markowitz and loaned by the U.S. Naval Observatory, is being installed to make frequent checks on the moon's position among the stars, so that slight irregularities in the P.Z.T. time (caused by slight changes in the earth's rate of rotation) can be revealed from comparisons made by the time obtained from the predicted positions of the moon.

Since the Oddie was the only telescope ready for use when work in stellar astronomy was resumed in 1945, a long series of measures of the relative positions of visual double stars was made by Woolley and Simonow with Gottlieb and later continued by W. D. Heintz. Several

new orbits were computed, and plans made to observe some of the pairs spectroscopically at future epochs when radial-velocity measures would strategically enhance the interpretation of their kinematical properties.

In addition to the facilities established on behalf of the people of Australia, universities in several nations overseas have sent equipment with their own staff to co-operate in studies of the southern sky from Mount Stromlo. The visits of Eggen, Gaposchkin, Dr. and Mrs. Kron and Wood from the United States have been mentioned above. As a result of the rapid growth and industrial activity of Johannesburg, the governing bodies of Yale and Columbia Universities decided to move their joint southern station to the Mount Stromlo ridge. C. Jackson is now continuing the observations with their 26-inch refractor for photographic determinations of stellar parallaxes and proper motions, and the motions of asteroids

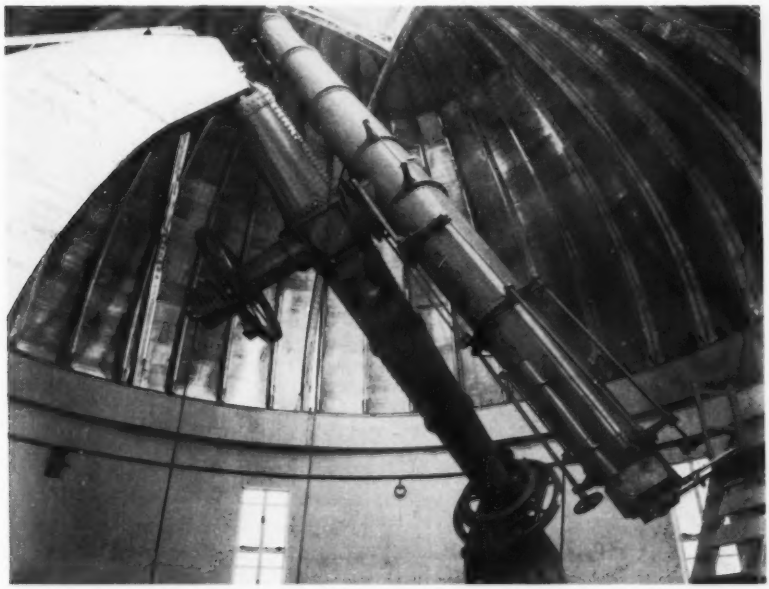

FIG. 3—The 26-inch refractor of the Yale-Columbia Southern Station.

and double stars. D. Brouwer (of Yale) spent several months in Australia when the rebuilding of the telescope was almost complete, to conduct the resumption of these programmes at the new site. J. Schilt (of Columbia), with Jackson, extended the work on stellar photometry

which they had begun in South Africa. Another contribution to work in astrometry was made with an 8-inch vertical circle from the University of Munich by Schmeidler and Heintz. During an 18-month visit they determined fundamentally the declinations of southern stars in the FK3 catalogue as a uniform extension of their own northern observations.

More recently G. Malmquist from Uppsala supervised the erection of a 20-inch Schmidt telescope with which B. Westerlund is now making a survey for red giants and supergiants in Milky Way fields and in the Magellanic Clouds. Plates are also being secured for an extensive study by Malmquist of the distribution of stars of different spectral types near the South Galactic Pole. The studies of objective-prism spectrograms will dovetail with the work on slit spectra taken with the larger reflectors. Bok, assisted by Mrs. J. Basinski, is obtaining photoelectric sequences with photographic magnitudes and colours for an extended study of this region (Selected Area 141), and Gascoigne is directly measuring photoelectric colours and magnitudes for the particular stars being classified by Westerlund, in collaboration with W. P. Bidelman of the Lick Observatory.

The National Science Foundation of the United States Government is supporting the establishment under auspices of Yale and Columbia Universities of a 20-inch astrograph (similar to the one operating at Lick Observatory) for the extension of surveys of the positions of faint stars and galaxies to the southern hemisphere. I. Epstein is at present testing the suitability of various sites in the northern parts of New South Wales, South and Western Australia, especially in areas remote from large cities and towns. At the same time, Bok is actively co-operating in this project, with a view to exploring just which regions of the vast continent may provide the most suitable sites for future erection of specialized optical telescopes.

Theoretical Studies. In connection with his earlier work at Cambridge and also at Mount Wilson on the photometry of Fraunhofer absorption lines in the solar spectrum, and measures of the colour gradients of bright stars at Greenwich and Mount Stromlo, Woolley was very much interested in the physical properties of stellar atmospheres. A series of theoretical papers on aspects of the solar chromosphere and corona culminated in a text-book, "The Outer Layers of a Star", of which D. W. N. Stibbs was co-author. This work was the stimulus for the very precise numerical computations by Przybylski which formed the basis for his papers on model stellar atmospheres. Assuming that the stellar atmospheres are in radiative equilibrium, he predicted values of the

colour gradient and strength of the calcium lines (*G* and *K*) in close agreement with the observed data for stars of various spectral types. More recently he has shown how sensitively the theoretical description of the solar atmosphere depends on errors in the observations of limb-darkening.

Toward the end of his stay in Australia, as the results of photometric researches were beginning to appear, Woolley turned his attention to the equilibrium of globular clusters. In a series of theoretical papers with various assistants he computed velocity and mass distributions and the times of relaxation after specified initial conditions, including a model in which relaxation had become complete only in the central region of a cluster.

From a combination of photoelectric observations of the light and colour variation with spectroscopic evidence on the changes in effective temperature and radial velocity, Rodgers found that the radius of Beta Doradus is abnormally large for its period. For classical Cepheids, the light variations are due mainly to changes in temperature, but for members of Population II the relative radius amplitude increases very rapidly with the period of pulsation.

Extra-mural Co-operation. Although there is as yet no national astronomical society in Australia, the interests of amateur telescope makers and observers are promoted by local associations in the various state capitals and a few smaller centres. For many years the interest of scientists working in other fields has been encouraged at assemblies of the Australian and New Zealand Association for the Advancement of Science, where fairly technical papers on current astronomical research are read, as well as more general survey lectures. In the past few years a widely felt need has been met through the arrangement of joint symposia from time to time in Canberra and Sydney to discuss new results and plan further collaboration between the optical astronomers of Mount Stromlo and the radio astronomers of the C.S.I.R.O. Laboratory. In these, as well as at the more frequent internal colloquia of the two separate groups, astronomers from Riverview and Sydney, physicists and mathematicians from Australian universities and overseas visitors often take part.

From the first establishment of the Commonwealth Solar Observatory, the scientists working on Mount Stromlo have always co-operated to the utmost with their colleagues overseas. The successive directors have taken active parts in the work of the International Astronomical Union, and several of the astronomers serve on commissions dealing with research in specialized fields. Prior to the departure of Australian delegates

to the recent Stockholm conference on the co-ordination of Galactic research, a small pre-conference was held in Canberra to explore related projects under way or about to commence at Australian observatories. The report of the introductory papers and full discussions was made available within a very few days for circulation to interested astronomers overseas.

University Incorporation. Even before the Observatory became formally associated with any University several scientists carried out their research work on Mount Stromlo to present new information in partial fulfilment of the requirements for advanced degrees at every Australian State University. When the Australian National University's Research School of Physical Sciences was established in 1950, the Commonwealth Astronomer (Dr. Woolley) was appointed Honorary Professor of Astronomy. The first thesis presented for a doctorate of philosophy from any department in the University was by Antoni Przybylski on the theory of

FIG. 4—Astronomers of the Mount Stromlo Observatory. Left to right, *seated*: H. Gollnow, K. Gottlieb, H. J. M. Abraham, A. R. Hogg, B. J. Bok, S. C. B. Gascoigne, T. Dunham, W. Buscombe. *Standing*: P. M. Morris, A. Przybylski, R. M. Henry, G. Hagermann, J. Crisp, D. G. Thomas, J. Banham, B. Westerlund, C. Wehner, H. Wehner, G. Oom, A. W. Rodgers.

model stellar atmospheres and its observational tests. The University's first Doctor of Science by examination, Gerard de Vaucouleurs, submitted publications on scientific photography, atmospheric and planetary physics and the study of galaxies, to all of which subjects he had made distinctive contributions during six years at Mount Stromlo.

As one may readily imagine, the transformation from a government department to a university devoted exclusively to research at the post-graduate level involves a major change of outlook for the Mount Stromlo Observatory. The Department of the Interior provided very generously for the accommodation and equipment of the Observatory during the generation before the Australian National University became a physical reality in Canberra. Within the University more flexible arrangements for the appointment of staff, and perhaps a more sympathetic appreciation of the needs of research work, should make possible the most effective use of the facilities available. The transition coincides with the appointment of Prof. B. J. Bok, formerly of Harvard, as Director to succeed Prof. Woolley who has become Her Majesty's Astronomer Royal. Prof. Bok's previous familiarity with optical study of the southern Milky Way and also with the observing techniques of radio astronomy augur well for a co-ordinated investigation of the southern sky from Australia.

Since no major courses of study in astronomy have been offered to undergraduates in any Australian university since 1890, it has been difficult to obtain locally young people interested in making a career in this field of science. The Australian National University offers very favourable opportunities for graduate study, and is considering co-operative arrangements under which lectures may be given in the State Universities. Positions are available, as in past years, for seasonal assistants who may obtain some experience of astronomical research during the university summer vacation. Through the University's provision for study leave, members of the academic staff may travel abroad to keep abreast of new developments in their fields, and the exchange of information is further encouraged as facilities are offered to astronomers visiting Mount Stromlo.

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CANADIAN SCIENTISTS REPORT-X

ASTRONOMY AT QUEEN'S UNIVERSITY

By A. Vibert Douglas

Queen's University, Kingston

In what is now Macdonald Park a building known as Kingston Observatory was erected in 1855 with funds provided by some generous citizens and by the Corporation of the city. By deed of Corporation in 1861 this observatory was transferred to Queen's University.

The new Principal, Rev. William Leitch who had been appointed in June 1860, and the professor of mathematics and natural philosophy, Rev. James Williamson who had been appointed to the Chair in 1842, were equally interested in astronomy and desirous of determining the exact longitude of Kingston. They devoted much time to the Observatory. The equipment included an Alvan Clarke equatorial with a 6¼-inch objective lens; a Short reflecting telescope with 7½-inch speculum mirror presented by Principal Leitch; and a small refractor presented by A. J. Macdonnell, Esq. The University erected a new building with a central dome, a transit room and a room for observers and the public. A Beaufrey Transit lent by the Royal Astronomical Society of London arrived during the session 1863 and was soon in operation. "A course of not less than six lectures in astronomy, open to the public, is delivered each year in the City Hall and the Observatory"—this announcement appeared in the university calendar for that year.

Nathan Dupuis, while an undergraduate, was appointed Observer in 1863 and subsequently became a member of the staff giving lectures in chemistry and natural history. He was made professor of mathematics in 1881, and was Dean of the Faculty of Practical Sciences from 1894–1911. He was a gifted teacher of mathematics and a genius in mechanical design and construction. He built sidereal and mean clocks for the Observatory and in 1887 he gave the university a clock with batteries to ring class-room bells. He designed and directed his students in the construction of the clock still operating (at least three of its four faces show the progress of the hours) in Grant Hall Tower.

In 1886 the university calendar promised that "Facilities for obtaining a knowledge of Practical Astronomy will be given students who apply to the Professor"—presumably Professor Williamson.

In the university calendar for 1891–92 an insert at the page listing the courses offered in physics under the direction of Professor Marshall, reads: "Fortnightly lectures and examinations on Astronomy by the Professor of Astronomy are to be attended by all students in the Junior Class in the Department of Physics." A student of that year, now Mrs. Etta A. Newlands, recalls that the professor was James Williamson, then 50 years on the Queen's staff and in the eyes of the students very old, very absent-minded, but highly revered. The lectures were given in a small frame building in the rear of the present Carruthers Hall. A stove provided inadequate heat, the professor wore two overcoats and one muffler about his neck and one around his waist! One of Professor Williamson's students of this period afterwards became a professional astronomer, S. A. Mitchell, who took his M.A. in 1894 and during the next session was appointed a tutor in physics and put in charge of the Observatory. In more recent years he has been widely known as the Director of Leander McCormick Observatory in Virginia, U.S.A.

In 1899 astronomy came under the control of Professor Dupuis in the Department of Mathematics where it has remained to the present time. Seven years later the instruments were moved to the foot of University Avenue and erected in a small but impressive limestone observatory built on a site purchased by the Chairman of the Board of Trustees, Mr. Justice Maclennan, and presented by him to Queen's University in 1906 for this specific purpose.

For several sessions beginning with 1899–1900 a course was given on Spherical Trigonometry, Geodesy and Astronomy. In 1907 it became Spherical Trigonometry and Astronomy, still under Professor Dupuis. In 1912 Theoretical and Practical Astronomy was substituted with Professor D. Buchanan in charge. He offered two courses in his last year at Queen's, 1920–21, Descriptive Astronomy and a one-term course in Spherical Trigonometry and Astronomy.

The following year Professor K. P. Johnston was appointed to the teaching staff in mathematics and until his retirement in 1946 he gave these courses with enthusiasm every winter and most summer sessions.

The present writer joined the staff of Queen's University as Dean of Women in the autumn of 1939 after seventeen years of lecturing in physics and in astronomy and astrophysics at McGill University with research work in the fields of spectroscopic absolute magnitudes, the

atmospheres of pulsating stars and high temperature stars showing Stark effect. In the summer of 1940 and on subsequent occasions she was invited to give Professor Johnston's courses. In 1946 the Department of Mathematics decided to drop the half-course in Spherical Trigonometry and Astronomy and the writer became acting Professor of Astronomy. Thereafter the course entitled Descriptive Astronomy became more heavily weighted towards astrophysics and it is now listed in the Arts calendar as An Introduction to Astronomy and Astrophysics. For some years it was given also every Summer Session. At the present time it is available every winter and at least every second summer.

In 1950 the writer offered a more advanced course for postgraduate students who were working towards the Master's degree or the Ph.D. in mathematics or physics. This course is now available every year.

The Observatory at the foot of University Avenue was a useful adjunct and was often used in the evenings, less often in the early morning hours before dawn, for the undergraduates in astronomy. It was demolished in 1946 to make way for the erection of the new Mechanical Engineering building, McLaughlin Hall. After that date students' observational work was restricted to the use of a small portable telescope, binoculars and the naked eye.

When plans for a new Civil Engineering building were under preliminary consideration in 1955, the writer approached the Principal, the Deans of Arts and Science and the Professor of Civil Engineering with the proposal that an observatory be erected on the roof. This suggestion met with their general approval and at Meetings of the Trustees and in the Building Committee it had also the wise and invaluable support of Dr. W. E. McNeill, Vice-Principal Emeritus of the University.

About this time, 1955, Dr. George A. Harrower became a member of the Department of Physics. With a background of wide training in electronics at both the University of Western Ontario and at McGill, and with research experience in physical electronics at the Bell Telephone Laboratories, New Jersey, and in radio astronomy with the Defense Research Board in Ottawa, he at once proceeded to establish radio astronomy at Queen's University. In two years much has been accomplished. Three postgraduate students are now enrolled, one at the Doctoral level and two for the Master's degree. A ten-acre site was leased in 1956 a few miles west of Kingston. A building was erected to house the necessary apparatus and provide observers' quarters. A radio telescope was built and put into operation early in 1957 and the construction of a second larger system was commenced.

Dr. Harrower has published seven papers on his researches before and

since coming to Queen's. His work on the cause of scintillations in discreet radio sources has already brought him distinction. His own brief description of his equipment in operation and under construction follows:

"Two types of measurements are being made: the study of the scintillation of the discrete radio sources and the recording of transient radio emissions from the sun. Both are intended to improve our present knowledge of the earth's ionosphere and of the factors which influence its behaviour.

"Scintillation measurements are made on the two brightest radio sources—those in Cassiopeia and Cygnus—which are monitored continuously. A second receiving system, including an antenna of somewhat greater resolving power, is intended to be used to study scintillations of the Taurus and Virgo sources. These two systems will permit comparison of scintillations in the northern and southern skies, the former being affected by the auroral zone. The scintillating signals are analysed both with regard to amplitude and frequency of the scintillations.

"The solar measurements are made on a radio spectrograph which scans a 25 Mc./s. range centred on 100 Mc./s. at the rate of once in three seconds. The measurements are recorded by means of an oscilloscope and photographic camera. This system permits the study of transient radio emissions occurring at the time of some solar flares, the distinguishing features of the phenomena being a duration of about three minutes and a downward frequency drift of approximately 0.2 Mc./s./s. The effect is believed to be caused by an outgoing stream of particles, the rate of radio frequency drift being determined by the velocity of the particles and by the properties of the sun's corona. These particles may reach the earth several hours later, contributing to the scintillation of cosmic radio sources and to other ionospheric phenomena."

The new optical observatory will be on the roof of the Civil Engineering building now being constructed on the west side of University Avenue about 300 yards north of Lake Ontario. The plans call for a dome room, two offices, two rooms for the use of graduate students, a seminar and library room, a workroom and a dark room. In the dome room it is expected that three instruments will be mounted on one polar axis, a 15-inch Cassegrain reflector, a 6-inch Catadioptic guide telescope, and a 3-inch astrograph. These instruments are now on order from J. W. Fecker Inc., Pittsburg. Attachments for spectrographic and for photoelectric work will provide simple research possibilities.

With this observatory functioning within the next two years Queen's University should have the necessary facilities to provide good undergraduate and graduate training in the oldest of the sciences.

One hundred years ago Professor Williamson taught astronomy and made a few observations in the little Kingston observatory in the Park, his determination of the longitude of Kingston* being 76° 32′ 07″. Fifty years ago Prof. Dupuis planned the grey stone observatory on Stuart Street and gave instruction in practical astronomy there. Now with the new optical observatory equipped with modern instruments and the radio observatory developing rapidly, astronomy at Queen's University should move forward with new vigour.

It was recently announced in the daily press that the Atkinson Charitable Foundation of Toronto has approved a grant of $25,000 to Queen's University. The grant is for the purchase and installation of the optical telescopes in the dome room, described in the above article—Editors.

*R.A.S.C. Journ., vol. 13, p. 7, 1919.

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

Miscellaneous notes on the activities of some of the more interesting variable stars, compiled from the plots of A.A.V.S.O. observations during 1957. Brightness is given in apparent visual magnitude.

001620 *T Cet.* This bright semi-regular variable had a maximum of about 5.7 the last of October.

001726 *T And.* An 8th magnitude maximum the last of February was followed by a 9th magnitude one in early December.

001838 *R And.* A bright maximum (6½) was observed in the middle of November, 410 days (the mean period) after the 1956 maximum, which was very bright and occurred about 30 days too early.

005840 *RX And.* This Z Camelopardalis-type variable was very erratic in its variations the first part of 1957, but in the observing season starting in June, it was quite regular, with a period of about 14 days and a range from 11 to 13.5 magnitudes.

011041 *UZ And.* A faint, 11th mag. maximum was observed in the middle of Aug.

012233 *R Scl.* This variable is one of the bright red variables, with less than 2 magnitudes range and a period of 376 days. It was almost constant at 6.3 for nearly 200 days during 1957.

014453 *TT Per.* Varied irregularly between 8 and 8½ magnitudes.

015912 *S Ari.* A very faint (11½) maximum observed in the middle of October.

020356 *UV Per.* A U Germinorum-type variable. No maximum observed in 1957.

021024 *R Ari.* A 9½ magnitude maximum, more than a magnitude fainter than normal, was observed in the middle of October.

021143 *W And.* A 9th magnitude maximum, in the middle of July, followed a 7th magnitude one in June 1956.

021403 *o Cet.* A very broad, flat, 4th mag. maximum was observed in November.

025751 *T Hor.* A 9th magnitude maximum in August follows an 8th magnitude one in early January.

032443 *GK Per.* Nova Persei 1901 varies erratically between 12.8 and 13.2.

043263 *R Ret.* Mean maximum magnitude is 7.7. The maximum in October was 11.2, and the three preceding ones, in decreasing order, were about 8.7, 9.6, and 7.5.

044349 *R Pic.* This semi-regular variable had about 1 magnitude range during 1957 instead of the published range of 3½ magnitudes.

050611 *Zinner 357.* Little variation during 1957.

054319 *SU Tau.* Nearly constant during the year.

054615a *Z Tau.* A nearly normal maximum of about 11th magnitude was observed early in February, following a very faint (12½) one in September 1955.

054705 *CN Ori.* Not much variation observed during 1957.

054974 *V Cam.* A bright, 8th magnitude, maximum was observed in late August.

055646a *RS Aur.* A range of nearly 2 magnitudes was observed during the year, following several years with a variation of about 1 magnitude or less.

060547 *SS Aur.* Six maxima were observed of this U Geminorum-type star.

063462 *RR Pic.* The magnitude of slowly fading Nova Pictoris 1925 decreased a tenth of a magnitude during the year, to about 11.5.

065530 *RS Gem.* Two minima fainter than 12th magnitude were observed in the middle of March and the middle of December. Normal minimum is about 11th mag.

072820b *Z Pup.* An 8.5 magnitude maximum was observed early in April, following one a magnitude fainter in 1955.

074922 *U Gem.* A narrow maximum, number 367, was observed by several members on New Year's Eve, 1958.

080835 *CP Pup.* Nova Puppis 1942 remains constant at about 11.2 magnitude.

081473 *Z Cam.* Nearly constant from March to June, then 2½ magnitude variation to the end of the year.

103769 *R UMa.* The maxima observed in the latter part of April was only 8½ magnitude, about 1 magnitude fainter than normal.

115158 *Z UMa.* This bright semi-regular variable had a broad, double-humped maximum with a 7th magnitude peak early in July and another in late August.

120012 *SU Vir.* A very faint maximum (11½) was observed in mid-March.

145971 *S Aps.* This R Coronae Borealis-type star had a drop of 1 magnitude during the summer, but returned to normal brightness in September.

151731 *S CrB.* The alternation of bright and faint maxima continues with a bright (6½) maximum in early June, following the faint (8) one in 1956.

154428 *R CrB.* Constant during the year.

165636 *RT Sco.* A bright 7½ magnitude maximum in the middle of October follows a 9½ magnitude one in July 1956.

174162 *W Pav.* A bright 8th magnitude maximum in early November follows 3 faint (10) maxima in 1955, 1956, and February 1957.

184243 *RW Lyr.* A normal (11½) maximum observed in mid-April follows a bright 10th magnitude one in October 1955.

190941 *RU Lyr.* A faint 11½ magnitude maximum the last of April follows a very bright 9½ magnitude one in April 1956.

191033 *RY Sgr.* An active R Coronae Borealis-type variable. About 8 months after recovery from the last minimum, it started to decrease again. It reached 10½ magnitude in October, then started a rapid rise to 8½ by the first of December.

192928 *TY Cyg.* A faint, 11th magnitude maximum in early July followed a 9½ magnitude one in late July 1956.

193449 *R Cyg.* A very faint, broad, 9th magnitude maximum was observed in early August. It is the faintest maximum observed for 10 years.

195109 *UU Aql.* Two maxima of this U Geminorum-type variable were observed about August 20 and October 12.

195656 *RR Tel.* A slow variation of 0.3 or 0.4 magnitudes seems to continue.

204104 *W Aqr.* A normal 9th magnitude maximum early in September follows a 10th magnitude one in September 1956.

205782 *T Oct.* A very faint maximum (10½) in mid-June follows a series of 9th magnitude ones.

210124 *V Cap.* A bright maximum (8.2) the last of June follows two 10th magnitude ones in 1955 and 1956.

213753 *RU Cyg.* After about a year of little or no variation, a 9.3 minimum was observed in the middle of May, followed by a maximum of about 7.6 the last of August.

213843 *SS Cyg.* Eight maxima were observed during the year, the last one on New Year's Eve. Observers were surprised that night by finding both SS Cygni and U Geminorum at maximum.

220714 *RS Peg.* A normal maximum (9.3) was observed early in September, following the very faint one (11.3) in September 1956.

220912 *RU Peg.* Three maxima were observed of this U Geminorum-type star, one the last of July, another the latter part of October, and the third the last of December, almost another New Year's Eve celebration.

225859 *UV Cas.* This R CrB-type variable has remained at maximum (11) since October 1956.

233335 *ST And.* Little variation has been observed for several years.

233815 *R Aqr.* A marked still-stand at 10th magnitude has been observed about 50 days before each of the last 2 maxima.

235150 *R Phe.* The alternation of bright and faint maxima has continued, with a faint 9th magnitude one observed in the latter part of May.

The variable stars listed below are all bright enough to be observed throughout their variations with binoculars or small telescopes. They are mostly irregular red variables, and observations are needed of all of them. The magnitude ranges are taken from recent A.A.V.S.O. light curves.

001620	T Cet	(5.5–7)
002235	AQ And	(8–9)
004181	RX Cep	(7.3–7.8)
011025	Z Psc	(7.0–7.6)
012233	R Scl	(6.2–8.0)
015654	XX Per	(8.3–9.0)
033362	U Cam	(8 –9)
042164	RY Cam	(8.5–9.5)
050001	W Ori	(6.5–7.5)
050611	Zinner 357	(5.5–6.5)
051532	UV Aur	(8.5–10)
053920	Y Tau	(7.5–8.5)
055122	BQ Ori	(7 –9)
060124	S Lep	(6.5–7.2)
060222	SS Gem	(8.8–9.5)
060426	TU Gem	(7.5–8.5)
060521	TV Gem	(6.5–7.5)
062938	UU Aur	(5.5–6.5)
065208	X Mon	(7.5–9)
065306	RV Mon	(7.5–8.2)
070311	W CMa	(7 –7.8)
072609	U Mon	(6 –7.5)
082405	RT Hya	(7.5–9)
083409	RV Hya	(7.5–8.2)
084917	X Cnc	(6.5–7.5)
085211	RT Cnc	(7.5–8.5)
090431	RS Cnc	(6 –6.8)
103212	U Hya	(5.2–5.8)
104620	V Hya	(7 –8.5)
112245	ST UMa	(6.5–7.5)
115158	Z UMa	(6.5–9)
121561	RY UMa	(7 –8)
123556	Y UMa	(8.5–9.5)
124045	Y CVn	(5.2–5.8)
125266	RY Dra	(6.8–7.5)
130802	SW Vir	(7 –8.2)
131546	V CVn	(6.8–8)
133674	V UMi	(7.6–8.5)
143532	RV Boo	(8.2–9)
154748	ST Her	(7 –8)
155436	RS CrB	(7.8–8.5)
155947	X Her	(6.2–7.2)
160325	SX Her	(8 –9)
162542	g Her	(5 –6)
163360	TX Dra	(7 –8.2)
164055	S Dra	(8 –9.2)
182621	AC Her	(7 –8.8)
183308	X Oph	(6.8–8.8)
183439	XY Lyr	(6 –6.8)
184205	R Sct	(5 –8.5)
192150	CH Cyg	(7 –8)
192576	UX Dra	(6.5–7.2)
192745	AF Cyg	(6.8–8)
193732	TT Cyg	(7.8–8.5)
200938	RS Cyg	(7.5–8.5)
202539	RW Cyg	(8 –9.5)
204017	U Del	(6.4–7.4)
204102	V Aqr	(8 –9.5)
213244	W Cyg	(5.3–7.2)
213231	AB Cyg	(7.6–8.2)
213735	V460 Cyg	(6.3–7)
213937	RV Cyg	(8 –9)
215927	TW Peg	(6.8–8.5)
222656	ST Cep	(7.8–8.8)
233451	SV Cas	(7 –9)
234102	TX Psc	(5.2–6)
234716	Z Aqr	(8.4–9.8)
235048	RS And	(8.4–9.4)
235659	WZ Cas	(6.6–8.5)

Observations received during November and December 1957: In November 4228 observations were received from 48 observers, and in December 3677 from 49 observers, a total of 7905 for the two months.

Observer	November		December	
	Var.	Ests.	Var.	Ests.
Adams, R. M.	90	150	97	203
Anderson, C. E.	85	125	39	57
Beidler, H. B.	8	8	..	..
Carlisle, J. H.	..	..	1	3
Chassapis, C.	39	267	..	..
Cragg, T. A.	120	120	323	325
*Darsenius, G.	12	41	11	21
Diedrich, DeL.	..	..	2	3
Diedrich, G.	..	..	6	9
Engelkemeir, D.	..	..	6	15
Erpenstein, O. M.	15	27	14	36
Fernald, C. F.	206	331	209	352
Ford, Clinton B.	120	123	130	132
Garland, G.	..	..	7	22
Gemberling, R. H.	17	32	11	15
Glenn, W. H.	20	20	..	..
Goldenblatt, P. P.	44	44	46	46
Gomila, R.	..	..	1	4
Goodsell, J. G.	..	..	4	4
Hartmann, F.	164	201	165	176
Hein, G. J.	1	12	5	6
Hutchings, N.	6	13	..	..
Kelly, F. J.	10	13	..	..
de Kock, R. P.	147	663	133	495
Kubanoff, J. H.	2	4	4	6
Lacchini, G. B.	61	133	50	73
Lowder, W. M.	42	74	7	7
McPherson, C. A.	7	7	7	7
Mebius, W. G.	7	18	..	..
Melville, E. C.	5	5	4	4
Miller, J. S.	7	7	7	16
Miller, W. A.	2	2	11	12
Montague, A. C.	29	44	31	39
Morgan, F. P.	17	39	22	41
Nestler, J.	..	..	1	1
Oravec, E. G.	206	505	218	518
Panke, D.	1	1	3	3
Parker, P. O.	25	39	25	27
Pearcy, R. E.	4	4	4	4
Pearlmutter, A. E.	..	..	63	186
Peltier, L. C.	27	89	25	100
Pilcher, F.	3	4	..	..
Price, F. J.	27	86	18	34
Renner, C. J.	155	177	..	..
Rizzo, P. V.	11	12	12	13
Robinson, L. J.	27	60	39	70
Rosebrugh, D. W.	18	144	17	114
Rosenfield, C. C.	1	1	1	1
Rosenfield, D. A.	1	1	1	1
Royer, R.	6	11	8	12
Segers, C. L.	25	42	30	74
Sharpless, A. P.	..	..	24	27
Socha, E. M.	2	5	2	2
Solomon, L.	27	35	..	..
Taboada, D.	163	175	151	260
Taulman, D. C.	8	16	..	..
Tsai, C. H.	91	296	..	..
Usakowski, C.	2	2	2	2
Valdez, M.	..	..	9	43
Venter, S. C.	..	..	28	56

*plus EV Lac 20m.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman): The following 8 observers checked their nova search areas for a total of 114 area-nights as indicated by the numbers after their names. The first number is the total for October, the second for November 1957.

Frank J. DeKinder: 18, 6; DeLorne Diedrich: 4, 4; George Diedrich: 9, 13; G. Harper Hall: 0, 3; Jane Shelby: 8, 9; Elizabeth M. Socha: 8, 6; James F. Wesling: 0, 9; Isabel K. Williamson: 14, 3.

We are very pleased to welcome the observations of our Canadian friends and must compliment them on making over 40 per cent. of the above observations. We have many more American names on our list than Canadian. Let us hope that serves as a hint to some of our "hibernating" observers. A thought in passing—with two naked-eye comets (even three for some) can a nova be far behind?? Keep looking!!!

NOTES FROM OBSERVATORIES

Dominion Astrophysical Observatory, Victoria, B. C.

Dr. Paul W. Merrill of the Mount Wilson and Palomar Observatories was Visiting Astronomer at the Observatory for the months of September and October, 1957, during which time he presented five scientific papers at staff seminars and held many discussions with individual astronomers.

Father M. F. McCarthy, S.J., spent about a month at the Observatory during October-November, studying spectra of late-type stars, and discussing with staff members the problem of absolute-magnitude effects on objective-prism spectra.

Other visitors at the Observatory included Dr. A. R. Hogg of the Mount Stromlo Observatory, Dr. A. Brown of Melbourne, and Dr. J. S. Foster of McGill University.

P. E. Argyle attended the December meetings of the American Astronomical Society held in Indianapolis.

A new building has been erected to house the machine and carpentry shops of the Observatory, previously located on the main floor of the dome building.

An automatic guider, designed and constructed by P. E. Argyle and A. R. Salonen, has been attached to the 72-inch telescope. This instrument and the exposure meter completed in the fall of 1955 have made it possible to use the telescope more efficiently and to obtain better spectrograms.

Through the co-operation of the Royal Canadian Navy and the Pacific Naval Laboratory it was possible for W. G. Milne and W. R. H. White to test the seismic recording apparatus of the Observatory network of stations, by means of depth charges dropped from vessels in the coastal waters. Preparations are now being made to make use of the shock waves produced by the Ripple Rock blast to be set off in April, in a study of the crustal structure of the earth in the region lying between here and the furthest network station in Alberta.

Jean K. McDonald

REVIEW OF PUBLICATIONS

The Inner Metagalaxy by Harlow Shapley. Pages vii plus 204; 6¼ × 9¼ in. Yale University Press, 1957. Price $6.75.

This book, by one of the best known astronomers, a former Director of the Harvard College Observatory, gathers together the main results of the vast observational programme on galaxies carried out for decades at that observatory. The observational results here summarized are based (like Halley's cometary computations) on a prodigious deal of work. The observers who ran the long, three-hour exposures with the big Bruce 24-inch refractor in the Andes of Peru or on the South African veldt, the observatory workers at their desks who patiently counted galaxies by the tens of thousands, and the director of the huge project, all have contributed.

Most of the material has already appeared in published form as a long series of papers. It involves counts and magnitudes for over a hundred thousand galaxies. It ranges in time from the Shapley-Ames catalogue of 1932, through counts of galaxies in the galactic polar zones, to relatively recent studies of cluster-type variables in our own galaxy. The author has not made the common mistake of holding the publication of his material for a completeness which is unattainable. The book is to be considered a discussion of Harvard work on galaxies, and not a summary of knowledge of galaxies from work at all observatories.

Five appendices contain exact observational material. Some of the conclusions from this material involve pitfalls which the author could not avoid, such as the assumption that the Kapteyn Standard Area magnitude sequences are accurate to magnitude 18. Improvement of the sequences may alter the interpretation of some of the observations.

As often happens when a series of papers is put together, the book seems like a compendium without a smooth flow from subject to subject. For example, all through the book in the figures, heavy shading in circles means large numbers of galaxies per square degree, until we come to figure 50, page 139, where we right about face, and heavy shading means no galaxies per square degree.

To this reviewer, the chapter on "The Star Clouds of Magellan, a Gateway to the Metagalaxy" (previously published in *The American Scientist*) is the best in the book. It is a balanced summary of informa-

tion on these Clouds, though the emphasis is still on the Harvard contribution. Photographs of the remarkable nebula, 30 Doradus, like the other pictures in the book, contribute to its attractiveness.

We are grateful to the author for gathering together in a convenient and attractive form the results of this great observational programme and for presenting it to us with his inimitable flair for words, as he works "from our awkward position near the edge of one dusty spiral". Along the way he tosses out his pithy ideas on galaxies—that his metagalactic census records 1,500 galaxies in the Bowl of the Big Dipper, accordingly the Hale telescope could photograph more than a million in it; and that "the local family is largely an illusion; it is probably little more than a group of six or eight conspicuous objects in a continuous field of dwarfish spheroidal and irregular galaxies of typically low luminosity".

HELEN SAWYER HOGG

The Galactic Novae by Cecilia Payne-Gaposchkin. Series in Astrophysics No. 1. Pages 336, 6½ × 9 in. Amsterdam, North-Holland Publishing Company, 1957. Price $8.50.

According to the author's own words, taken from the Preface, her aim was "to summarize the known data that should form the starting point for an interpretation of the nova process". This aim has certainly been achieved.

This book contains not only vast material, enriched by numerous tables, and bibliography about all novae which could be found in the literature but also a critical examination of physical processes which determine the novae phenomena. Spectral changes are linked to photometric data through different stages of a nova outburst and the development of detached shells is explained. Then different types of explosive stars are examined and points of similarities and differences are stressed. The final chapter deals, partly on a speculative basis, with the position of novae on the Hertzsprung-Russell diagram and with their most likely evolutionary pattern. As for the theory of novae processes some nuclear reactions are discussed which could supply the necessary energy.

The chapters are as follows: Statistics of Galactic Novae; Distribution of galactic novae, The spectra of novae, The spectra of novae, Galactic novae, first class, second class, and fragmentary data, The symbiotic novae, The U Geminorum and Z Cameloparadalis stars, The supernovae, Comparative study of spectral development, Evolutionary and theoretical problems.

The book is attractive in appearance. There are a few small mistakes and misprints which, however, do not distort the text.

To professionals and students alike this book will be a valuable source of information and one can only recommend it.

G. A. Bakos

Astronomischer Jahresbericht, vol. 55, published by the Astronomischen Rechen-Institut. Pages 542, 6 × 9 in. Berlin, Walter de Gruyter and Co., 1957. Price 50.-DM.

This German periodical lists the astronomical literature which appears during a year under fourteen main classifications; all papers are briefly summarized in German. It is a most valuable reference work for astronomers. The present volume covers the literature for the year 1955 and includes 13,452 entries.

Editor

Der Sternenhimmel, 1958 edited by Robert A. Naef. Pages 126, 6 × 8¼ in. Aaru, H. R. Sauerlander and Co. Price Swiss Fr. 7.80.

This small astronomical yearbook is sponsored by the Swiss Astronomical Society. The general arrangement is similar to that of many other handbooks, and it is illustrated with charts and diagrams. Special attention is given to occultations of stars by the moon and planets, to eclipses and to asteroids. A useful addition is a map of the surface of the moon and a diagram of visibility of planets. The book includes a list of interesting objects by constellation and a short dictionary of astronomical terminology.

Amateur astronomers who read German may find in this yearbook a useful addition to their library. It may be ordered from Mr. Albert J. Phiebig, P.O. Box 352, White Plains, N.Y., U.S.A.

G. A. Bakos

NOTES

Le Centre Français de Montréal a dix ans

Le 18 mai 1957, Le Centre Français de la Société Royale d'Astronomie célébrait le dixième anniversaire de sa fondation. La Ville de Montréal, représentée par le Dr Ruben Lévesque, recevait à dîner la section française qui célébrait son 10ième anniversaire.

L'Acfas et l'Institut Franco-canadien furent les parents du Centre Français de Montréal. Parmi les anciens présidents: M. DeLisle Garneau, fondateur de l'Observatoire Ville-Marie, Mlle Marcelle Gauvreau, botaniste distinguée, feu Arthur Amos, Ing.P., et parmi les autres fondateurs, feu le Fr Robert f.e.c. et M. Jean-Jacques Lefevbre, archiviste de la province de Québec.

M. Jean Asselin, Ing.P. président actuel constate combien l'astronomie est redevenue populaire en ces dernières années, surtout depuis que l'on parle de lancer des satellites, et en certains milieux, de se servir de ces satellites pour transporter des humains.

En 1868, huit amateurs fondaient le Toronto Astronomical Club, d'où est issue en 1903, par charte d'Edouard VII, la Société Royale d'Astronomie du Canada, qui compte aujourd'hui seize cents membres canadiens et quatre cents adhérents en d'autres pays.

Parmi la cinquantaine d'amateurs qui constitue le centre français, il y a des astronomes de toutes catégories nous dit monsieur Asselin: des jeunes, des vieux, des savants, des religieux, des femmes, des riches, des pauvres, surtout des pauvres, qui possèdent cette noble curiosité de l'homme, qui essaient de saisir un peu du mystère de la création, de sonder cet abîme qui effrayait Pascal.

N'allons pas imaginer que ce sont là des gens qui ont satisfait leur curiosité par la simple lecture de Flammarion ou de Moreux, par la "découverte" de la Polaire ou d'une constellation. Ils ont une passion: l'astronomie, et cela s'étend aux instruments. L'un se montre très habile constructeur de télescopes; un autre est un remarquable polisseur de miroirs de télescopes.

Outre M. Asselin et le Dr Ruben Levesque, ont adressé la parole à ce dîner, Mlle Marcelle Gauvreau, et M. Charles M. Good président de la section montréalaise de langue anglaise.

Fleurange Laforest

OBITUARY: MAJOR REX GIBSON

The Victoria Centre of the Royal Astronomical Society of Canada lost one of its most famous and valued members in the death on August 20, 1957, of Major E. Rex Gibson, M.C. His death occurred on Howson Peak in the coastal mountain range near Terrace, B.C., following an accident in which his two companions suffered severe injuries.

Major Gibson was one of the foremost mountaineers in North America, and for the past three years has held with distinction the high mountaineering office of President of the Alpine Club of Canada. During the last world war, as a Canadian Liaison officer, he was jointly in charge of the training given in the Canadian Rockies to the Lovat Scouts, a British regiment being instructed in high mountain warfare. He was, as well, the Canadian representative on the United States expedition which climbed Mt. McKinley in Alaska, during a series of tests of army clothing, equipment and techniques for cold mountainous regions.

Rex Gibson was born in England and came to Canada in the 1920's. He farmed near Edmonton, and it was there that his association with the R.A.S.C. began some thirty years ago. At the time of his death he was First Vice-President of the Victoria Centre, he having resisted the efforts of the Centre to make him the President last year, because of the heavy duties he still held with the Alpine Club of Canada.

During his more than three decades in Canada, Rex Gibson has generously and enthusiastically shared with young people his skill in outdoor sports and his knowledge and appreciation of the wonders of the earth and the sky. A lecture he gave to astronomical and school groups on "Mountaineering on the Moon" combined his two great interests, mountaineering and astronomy.

Major Rex Gibson was married in 1948 to Miss Ethne Gale of Saanichton, B.C., and the sympathy of the Society is extended to her and to their small daughter, Kathleen.

JEAN K. MCDONALD

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David Dunlap Observatory, Richmond Hill, Ontario

The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of either of these publications are 75 cents.

Membership, which includes the publications, is open to anyone interested in astronomy. Annual dues are $5.00; life membership is $75.00. Application for membership or publications should be made to THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, 252 COLLEGE STREET, TORONTO 2B, ONTARIO.